

Earth Construction – Bird Teaching

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Abstract: - The paradigm of earth being a traditional and a modern building material has been related to the fact that it is natural, ecological, recycled, abundant and economic. Among the traditional Portuguese building techniques, earth construction was always one very common. The construction built with these techniques must be preserved. In this context, the main objective of this research work is to give a contribution on the material properties characterization and, in particular, for the development of adequate rehabilitation and strengthening techniques for this type of construction, based upon a biomimetics study focused on the *andorinha-dos-beirais* nest. A structural numerical model of a nest using a finite element computer analysis program was done in order to understand the structural behavior of this kind of natural structures. In order to identify a possible occurrence of a certain agglutination phenomenon during the building process of the nest by the birds, an experimental identification/characterization study of nest's material using samples taken in Vila Real area was carried out. The identification of the elementary chemical and the mineralogical compositions of the material were done by the scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and by the X-ray diffraction analysis, respectively. The identification/characterization of the organic composition was done using the colorimetric method, being the protein components detected by the biuret method and the polysaccharides/sugars components by the total sugar method. The identification of the type of polysaccharides/sugars and their amount was done by the anion-exchange chromatography method. In order to verify if the addition of polysaccharides/sugars into the nest's material results in an improvement of the mechanical properties, in particular, of its compressive strength, mechanical tests were carried out on cubic specimens. The results show that there is a strong possibility of the bird *andorinha-dos-beirais* adds a certain amount of glucose into the clay material during the building process of the nest, which may increase the quality of this raw material.

Key-Words: - Raw materials, Earth construction, Biomimetics, Nest bird, Characterization, Finite element analysis

1 Introduction

Half of the world's population approximately, 3 billion people on six continents, lives or works in buildings constructed of earth [1]. In the third world countries almost half of the existing buildings are made of earth [2]. The earth construction is a worldwide heritage that reflects the existing cultural diversity of people [3]. Examples of ancient earth constructions are: the China Wall (2000 B.C.) [4]; and, the Arge Bam city in Iran (500 B.C.) [5]. This impressive earth heritage also reveal that earth construction can have a very sustained durability. At the same time, cutting edge modern earth constructions, such as: the Adobe Repository for Buda Statue in Japan (2001 A.D.) [1]; and, the Desert Cultural Centre in Canada (2006 A.D.) [6], prove that earth based building materials are nowadays in demand.

Earth based building materials are sustainable, in one hand because earth is natural, recyclable and abundant anywhere in the world, and in the other hand because the techniques used to manufacture these materials are usually simple, requiring an unexpressive amount of energy consumption and also having an unexpressive amount of CO₂ emissions associated. The building materials and the building techniques related to earth construction have been developed constantly, the emerging quinha metálica technique [7] which intends to replace a traditional timber structure system by a metallic one keeping the traditional earth covering of the system is just one example.

Biomimetics has been applied in several fields of science. In the medicine field, for instance, a bioartificial kidney has been developed [8]. In civil engineering

applications, an active prestressing technique has been proposed and developed based on the functioning of the human biceps [9].

In this research work, the *andorinha-dos-beirais* bird nest is the biomimetics material and structural model used in order to derive information that may contribute to the quality improvement of earth based building materials properties, such as its durability, workability or mechanical performance. Other natural earth structures are for example the termite nest [10] and the wasp solitary nest [11].

In this context, a numerical model of the *andorinha-dos-beirais* bird nest was developed, with a computer finite element analysis program, in order to understand the structural behavior of this natural structure. In order to study the eventual agglutination phenomenon during the building process of the nest, an experimental testing campaign for the identification/characterization of the nest's material using samples gotten in the Vila Real area was carried out. The identification of the elementary chemical and mineralogical compositions of the material samples were done by the scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and by the X-ray diffraction analysis, respectively. The identification/characterization of the organic composition was done using the colorimetric method, for which the protein components were detected by the biuret method and the polysaccharides/sugars components by the total sugar method. The type of polysaccharides/sugars identification and their amount quantification was done by the anion-exchange chromatography method. With the purpose of verifying if the addition of these polysaccharides/sugars into the admixture material used for the nest construction, mechanical tests on produced samples were performed. The test results show that there is a strong possibility of the *andorinha-dos-beirais* adds a certain amount of glucose into the clay material during the building process of the nest. This component may change the properties of the earth-based material increasing the performance of this raw material.

2 *Andorinha-dos-beirais* Bird

The *andorinha-dos-beirais* bird, *Delichon Urbicum* [12], is a migratory bird. In average, the length of the *andorinha-dos-beirais* is 12.5 cm and its weight is 18.3 g [13]. Each lay includes four or five eggs (1.9 cm length, 1.3 cm diameter and 1.7 g weight). Usually, there are two lays per estival period. The nest is used for both lays of the year, and can also be used by the beards in the following years. This fact requires that the *andorinha-dos-beirais* has to repair the nest, which is a natural structure made of clay gotten in the surrounding

areas, before each lay. Fig.1 shows the *andorinha-dos-beirais* and also its nest.

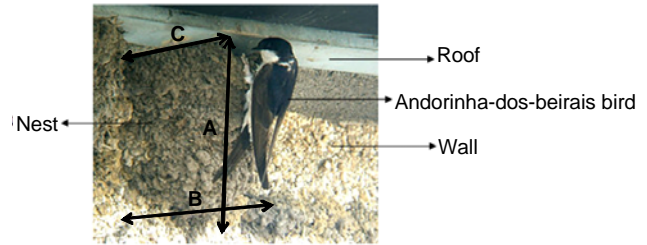


Fig.1 - *Andorinha-dos-beirais* and its nest [14]

Among other countries of Europe, this bird also spends the estival period in Portugal and, in particular, in the Vila Real city, which is the capital of Trás-os-Montes e Alto Douro region, the northeast part of Portugal continental, where this research work has been developed.

3 The Nest of the *Andorinha-dos-beirais*

It is very common to find *andorinha-dos-beirais* bird nests in urban areas and especially near the watercourses. In Fig.1 it is shown a nest built upon the façade of a house, in the junction of the wall and the roof, which allows two contact surfaces for the support of the nest and protects the nest from the rain and predators. It can be observed in Fig.1 that the size of the clay particles used by the *andorinha-dos-beirais* bird tends to decrease from the bottom to the top of the nest.

The six nest samples used in this research work were gotten in three different locations of Vila Real city, which are São Dinis, Mateus and Noura. Table 1 presents the weight and the geometric dimensions of the six samples, namely height (A), width (B), depth (C) and average value of thickness (D) (see also Fig.1).

Table 1 - Data of the nest samples

Sample nest		Weight (g)	Dimensions (cm)			
#	Location		A	B	C	D
1	São Dinis	388	12.7	18.3	7.4	2.1
2	São Dinis	414	12.3	17.7	8.1	2.2
3	Mateus	375	11.6	17.6	7.8	2.1
4	Mateus	584	13.2	18.2	8.2	2.2
5	Noura	393	11.8	18.3	7.7	1.9
6	Noura	403	12.1	18.4	7.9	2.2

In the experimental identification/characterization tests of the nest material, which will be presented and discussed in the following sections, the three material samples studied were obtained by mixing up six portions of material collected from six nests in the three areas, two from each area (see Table 1), resulting therefore in three different material nest samples.

4 Structural Behavior of the Nest

In order to understand the structural behavior of the nest, as a natural earthen structure, a finite element analysis was done using the commercial code ANSYS® [15]. For this purpose, a numerical model of the nest was defined using solid hexaedric isoparametric elements of 20 nodes (SOLID95). For the dimensions of the model it were adopted the average values of the geometric dimensions presented in Table 1. The finite element mesh generated for the nest simulation is presented in Fig.2. The opening on the top of the nest was not considered within this model to simplify the results interpretation.

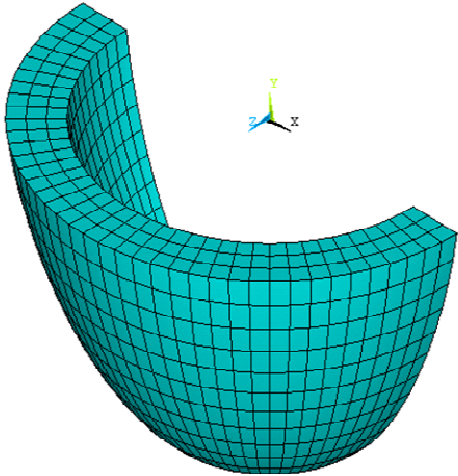


Fig.2 - Finite element mesh of the nest

The nest material was assumed to be isotropic and linear elastic, with a volumetric weight of 18 kN/m^3 , an elastic Young modulus of 1 GPa and a Poisson coefficient of 0.25 . The support conditions of the nest (related to the connection of the nest to the wall and roof) were simulated in the numerical model blocking the contact nodes for the displacements in the three independent directions.

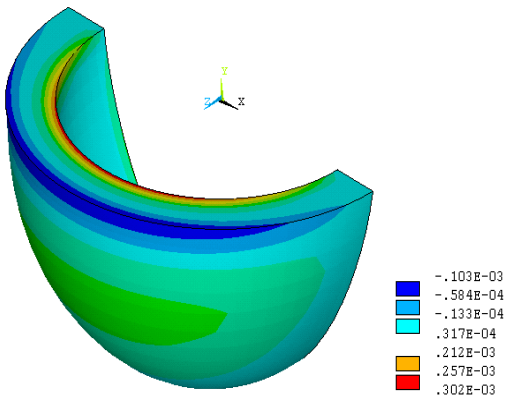


Fig. 3 - Normal stress distribution for the y direction (σ_y), MPa

The worst loading scenario considered in this structural analysis was considering the self-weight of the nest plus the weight of six adult *andorinha-dos-beirais* birds (five broods and one progenitor). The normal stress distribution for the vertical y direction (σ_y) resulted from the analysis of the nest under the described loading scenario is represented in Fig.3.

The above stress distribution diagram indicates that the nest is mainly under compression normal stress and the maximum compression value of 0.10 kPa is small than the compression capacity of $-0.5\text{E-}03 \text{ MPa}$ of an adobe masonry wall [16] for instance. According to Fig.3, only a small part of the nodes that simulates the contact between the nest and the roof, on the inside surface, is an exception because they are under tension stress. This fact is interesting because a traditional earth construction is not supposed to be working in tension. This information indicates that the *andorinha-dos-beirais* bird is a very refined earth construction designer.

5 Identification/Characterization of the Nest Material Samples

As it was stated above, the nest of the *andorinha-dos-beirais* bird is built up using a natural material, a clay based soil. In order to verify the composition and to check if the *andorinha-dos-beirais* bird adds any other component to the clay during the building process of its nest, several experimental tests were carried out, such as: scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS), X-ray, colorimetric method using the biuret and the total sugar methods, and also the anion-exchange chromatography.

In this context, material samples extracted from the nest selected within the Vila Real region, and previously presented in Table 1, and also an additional clay sample (here labeled as “reference sample”) extracted from a watercourse in the surrounding area were used in this study. The reference sample showed to be of extreme helpful during the experimental results analysis, as will be presented next.

5.1 SEM/EDS Test

In order to identify the elementary chemical composition of the nest material samples, SEM/EDS tests were performed in the Electronic Microscopy Laboratory of the Trás-os-Montes e Alto Douro University (UTAD), shown in Fig.4. The SEM/EDS experimental results obtained are presented in Table 2.



Fig.4 - Electronic microscopy equipment used

Table 2 - SEM/EDS experimental results

Element (%)	Sample			
	Reference	São Dinis	Mateus	Noura
Oxygen (O)	48.12	45.67	41.72	46.80
Sodium (Na)	0.69	0.81	0.42	1.43
Magnesium (Mg)	0.89	0.33	0.75	1.10
Aluminium (Al)	12.90	15.54	15.54	12.60
Silicon (Si)	29.04	27.47	33.08	27.85
Chlorine (Cl)	0.00	0.99	0.00	0.09
Potassium (K)	3.62	6.22	2.89	3.45
Calcium (Ca)	0.00	0.00	0.00	0.61
Titanium (Ti)	0.38	0.21	0.48	0.57
Iron (Fe)	4.36	2.76	5.12	5.50

According to the data of Table 2, the elementary chemical composition of the nest material samples, as well as in the clay of the reference sample, are very similar. For all the samples, Silicon (Si) and Aluminium (Al) are the most expressive chemical components, apart from the oxygen (O).

5.2 X-ray Test

X-ray tests were performed, also in the Electronic Microscopy Laboratory of UTAD, with the purpose of indentifying the mineralogical composition of the nest material samples. A PANalytical model X'Pert PRO with a detector of X'Accelerator equipment, Fig.5, was used.



Fig.5 - PANalytical model X'Pert PRO with a detector of X'Accelerator equipment

The X-ray test results obtained are presented in Fig.6, where the diffraction curves of the four material samples tested (reference, Mateus, São Dinis and Noura) are represented. The mineral composition of the four samples is similar and presents the following minerals:

clinocloro, aluminum potassium silicate, quartz and muscovite.

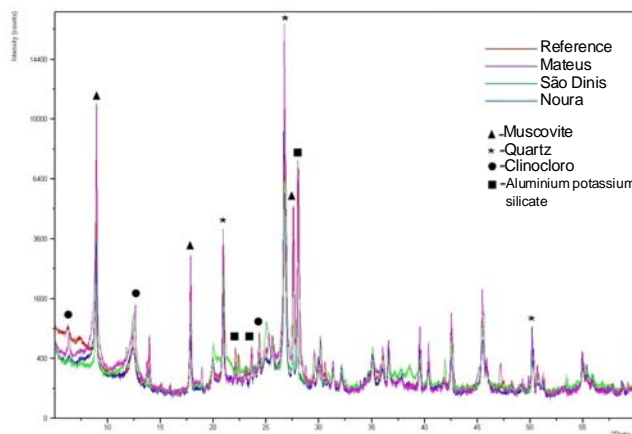


Fig.6: X-ray test results

5.3 Colorimetric Method

The organic composition of the material samples were identified by the colorimetric method in the Fine and Applied Chemical Laboratory of UTAD. This identification process was developed intending to detect the presence of proteins or polysaccharides/sugars, the possible organic polymer components of the nest material. For the detection of the presence of organic protein components in the nest material the biuret method was followed, on the other hand the detection of the presence of polysaccharides/sugars in the samples was done following the total sugar method [17]. In this paper, and for simplification purposes, only the São Dinis nest material sample and the reference sample are here analyzed. Fig.7 illustrates the steps of this test procedure.

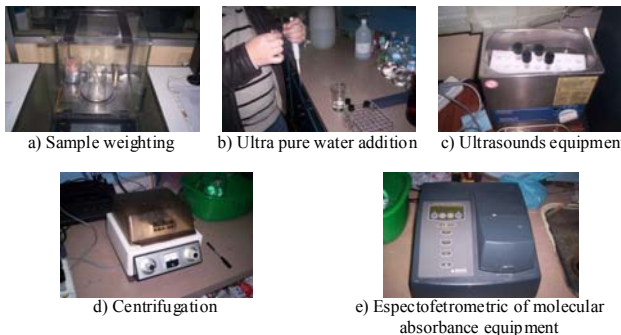


Fig.7 - Steps of the colorimetric method test and equipment used

The adopted reagents in the biuret and total sugar testing methods were proteins and sulfuric acid, respectively. The results of this colorimetric method are presented in Table 3, where the ultra pure water sample (Table 3, 3rd column) is a comparative indicator.

Table 3 - Results of the colorimetric test

Test		Sample				
		Ultra pure water	Reference		São Dinis	
Molecular absorbance	Biuret	0.156	0.174	0.176	0.127	0.138
	Total sugar	0.220	0.340	0.580	1.366	1.142

Comparing the molecular absorbance values obtained by the biuret methodology for the reference and the São Dinis nest material samples, it is concluded that both samples have similar values and also similar to the obtained for the ultra pure water sample. This information indicates that there is no significant quantity of protein components in all the material samples tested.

On the other hand, after doing a similar analysis but using the total sugar method, a completely different conclusion results. The molecular absorbance for the São Dinis nest material sample is significantly higher than the similar value obtained for the reference sample and for the ultra pure water sample (Table 6). This conclusion indicates that nest material has an amount of polysaccharides/sugars components which is significantly superior to the respective amount existing in the reference sample (clay). Therefore, it is deduced that the *andorinha-dos-beirais* bird may add these polysaccharides/sugars components during the nest building process.

Based upon these observations and in order to confirm these results, a second series of the colorimetric tests was done focused on the total sugar method, using nest material samples of Mateus, São Dinis and Noura and, with a 90 minutes ultrasounds duration. The experimental results obtained in this second test series are presented in Table 4.

Table 4 - Total sugar method results

Sample				
Ultra pure water	Reference	Mateus	São Dinis	Noura
0.220	0.392	0.702	1.812	0.427

The results presented in Table 4 confirm the conclusions achieved in the first test series. However, the Noura nest material sample shows a value of molecular absorbance only slightly superior of the respective value obtained for the reference sample (clay).

5.4 Anion-exchange Chromatography Test

In order to identify the type of the polysaccharides/sugars components of the nests sample material, and to quantify these components, an anion-exchange chromatography test was developed in the Chromatography Laboratory of the UTAD. The polysaccharides/sugars were extracted from the samples by hydrolysis procedure. The types of polysaccharides/sugars checked were the more common in nature [18], which are the following: fucose (Fuc),

arabinose (Ara), galactose (Gal), glucosamine (GlcN), glucose (Glc), mannose (Man) and xylose (Xyl). The results obtained by this test are presented in Table 5.

Table 5 - Results of anion-exchange chromatography test

Sample	Fuc (mg/g)	Ara (mg/g)	Gal (mg/g)	GlcN (mg/g)	Glc (mg/g)	Man/Xyl (mg/g)	Total_1 (mg/g)
Reference	0.014 (1.7%)	0.177 (21.5%)	0.174 (21%)	0.00 (0%)	0.332 (40%)	0.128 (16%)	0.825 (19%)
Mateus	0.017 (1%)	0.220 (15%)	0.156 (11%)	0.257 (17%)	0.614 (42%)	0.208 (14%)	1.472 (35%)
Noura	0.020 (3%)	0.116 (20%)	0.105 (10%)	0.00 (0%)	0.248 (44%)	0.077 (14%)	0.565 (13%)
São Dinis	0.013 (1%)	0.202 (15%)	0.571 (42%)	0.00 (0%)	0.427 (30%)	0.165 (12%)	1.379 (33%)
Total_2 (mg/g)							4.241

According to the results presented in Table 5, all the material samples tested, including also the reference sample, have polysaccharides/sugars in their composition. The Mateus and São Dinis nest material samples have higher percentage of polysaccharides/sugars (35% and 33%, respectively) than the Noura nest material sample and the reference sample (13% and 19%, respectively). In terms of polysaccharides/sugars contents, the nest material sample which is more similar to the reference sample is the Noura nest material sample.

Considering the possibility of the *andorinha-dos-beirais* bird adding a certain quantity of polysaccharide/sugar to the nest material during its building process, in the following it is analyzed the type of polysaccharides/sugars founded in nest samples with contents superior to the reference sample. The results of Table 8 indicate that the polysaccharide/sugar type may have an important content of Glc, because the Mateus and Noura nest material samples have 42% and 44% Glc, respectively, while the reference sample has 40%.

For some samples, the percentage of polysaccharides/sugars is higher than the value found for the reference sample, such as: 17% of GlcN in the Mateus nest material sample while 0% of GlcN in the reference sample; 42% of Gal in the São Dinis nest material sample in contrast with 21% of Gal in the reference sample; 3% of Fuc in the Noura nest material sample in contrast with 1.7% of Fuc in the reference sample.

Based upon these results, it may be concluded that there is a strong possibility of the *andorinha-dos-beirais* bird adds a small amount (approximately 3%) of glucose (Glc) into the nest material during its building process. Meanwhile, the discrepancy found in the test results indicates that the clay material used as reference sample could be not representative of the clay used in the construction of the nests. Thus, further research work needs to be done in this matter using more clay samples from the region.

6 Mechanical Tests

In order to verify if the addition of polysaccharides/sugars into the nest material results in an increasing of the mechanical properties, particularly in its compressive strength, mechanical tests were performed at the Materials and Soil Mechanics Laboratory of the UTAD, on fabricated cubic specimens. Two different series of material samples were manufactured using clay based soil extracted in the same watercourse from where the reference samples presented in the previous section were gotten.

The first material samples (I) were manufactured by mixing the clay based soil with 50 cl of ultra pure water. The second samples series (II) consisted on mixing the clay based soil with 50 cl of an aqueous solution extracted from the nest material.

The extraction process of the polysaccharides/sugars from the nest material was done according to the procedure summarily illustrated in Fig.8. First, the nest material samples were cleaned up and triturated (Fig.8-b). Then, the organic components of the nest material samples were extracted mixing up 250 g of the triturated nest material with 50 cl of ultra pure water, during 1 hour (Fig.8-c). Finally, the extracted aqueous solution was filtered, avoiding the weight increase of the samples (Fig.8-d).

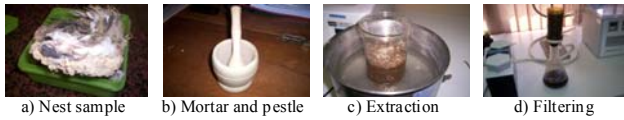


Fig.8 - Polysaccharides/sugars extraction procedure

Three cubic specimens (approximately 4 cm side) of each material series were manufactured and tested in compression with the Compression Testing Machine BETA 5equipment (Fig.9-a), after seven days drying at the laboratory temperature. Fig.9-b shows a cubic specimen after being tested in compression.

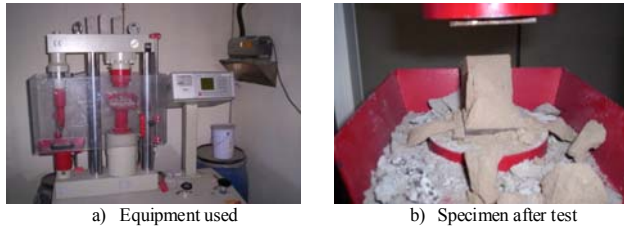


Fig.9 - Compression test

The results obtained by the compression tests are presented in Table 6, for the three cubic specimens of each material sample series.

Table 6 - Compression strength (MPa)

Specimen					
I-1	I-2	I-3	II-1	II-2	II-3
0.27	0.65	0.49	0.71	0.68	0.76
Average (series I): 0.47 MPa			Average (series II): 0.72 MPa		

The results presented in Table 6 indicate that the specimens manufactured with polysaccharide/sugar components (series II) have higher compressive strength than the specimens which did not have the addition of these components (series I). This fact suggests that the inclusion of polysaccharides/sugars into the nest material may increase its mechanical properties. This conclusion achieved may be of great interest for the structural performance and safety improvement of the earth based buildings.

Amplified microscopic images obtained for the material samples type I (Fig.10-a) and II (Fig.10-b) also suggest that there is a pronounced morphologic difference between each sample series, due to the agglutination process in samples II produced by the addition of polysaccharides/sugars.

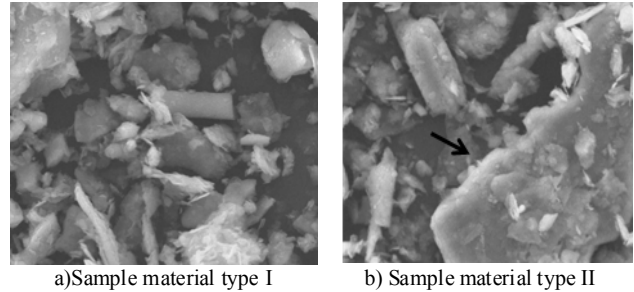


Fig.10 - Amplified microscopic images

7 Main Conclusions

The nest of the *andorinha-dos-beirais* bird is a natural structure built with clay and may be used as a biomimetics model in the earth construction improvement.

It is common to find *andorinha-dos-beirais*' nests in urban areas and, particularly, near watercourses. The average geometrical dimensions of the nest of *andorinha-dos-beirais* bird are: 12 cm height, 18 cm width, 8 cm depth and 2 cm wall thickness.

The nest, as an earth-based construction, has a remarkable durability, since it is used by the birds for several years.

By the numerical modeling of a nest structure with average dimensions, it was realized that this structural system has installed mainly compressive normal stresses.

SEM/EDS and X-ray tests have shown that the chemical and mineralogical compositions of the nest material are similar to the local clay.

Colorimetric tests have shown that there is not an expressive amount of organic proteins component in the nest material. On the other hand, this test allowed to conclude that there is a strong possibility of the *andorinha-dos-beirais* bird adds a certain amount of organic polysaccharides/sugars components into the material used during the building process of the nest.

The process followed for the identification of the polysaccharide/sugar type present in the nest material revealed to be very complex. This identification was done through the chromatography ion test. The results obtained, even if not totally consistent, indicates that the glucose may be the polysaccharide/sugar naturally added by the *andorinha-dos-beirais* bird. Further research has to be done in this subject using a more representative series of clay and nest samples.

Mechanical tests performed suggest that the addition of the polysaccharide/sugar into the nest material may increase the mechanical properties, in particular the compression strength. Microscopic analysis also suggests that the inclusion of these organic components may induce an agglutination process. This information can be extrapolated and used in the improvement of earth based building materials.

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